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Barndoor skate in the Northwest Atlantic off Canada: Distribution in relation to temperature and depth based on commercial fisheries data

La grande raie dans l'Atlantique Nord-Ouest au large du Canada : répartition en fonction de la température et de la profondeur d'après les données de pêche commerciale

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Abstract

Commercial fisheries data were used to examine the distribution of barndoor skate in Canadian waters. Bycatch in the commercial fisheries shows that the distribution of barndoor skate extends much further north than indicated by survey data, indicating their presence along the shelf edge as far north as Lat. 62^0 N. Between 1980 and 2001, over all areas and depths fished, barndoor skate were taken in 7 commercial gears, primarily in otter trawls and longlines in 1 set in 200 on average. Percent occurrence was used to define relative abundance in relation to temperature and depth. Spatial differences in catch rates (based on weight) reflected local density or perhaps the presence of larger (heavier) fish. Barndoor skate are widespread in terms of depth across its entire range although their depth distribution varied among areas. On the western Scotian Shelf, both catch rates and percent occurrence of barndoor skate were about 10 times higher at depths exceeding 450 m. Considering that ninety-nine percent of survey sets in this area were prosecuted at depths < 450 m, this indicates that the surveys cover only a fringe of the total distribution in that area. Thus, indices based on surveys underestimate abundance and may not reflect population trends. They may represent shifts distribution into and out of the surveyed area rather than trends in abundance. In terms of bottom temperature, very few barndoor skate were taken where temperature was < 1.5^0C even though substantial proportion of the fishing effort occurred there. To the north, barndoor skate were associated mainly with temperatures of 2-4.5^0 C, to the south, 4-9^0 C. The difference between the two areas likely relates to different depths (and associated temperature ranges) fished.

Résumé

Nous nous servons de données de pêche commerciale pour étudier la répartition de la grande raie dans les eaux canadiennes. Les données de prises accessoires révèlent que la grande raie est présente le long de l'accore du plateau jusqu'à 62° de latitude nord, soit beaucoup plus au nord que ce qu'indiquent les relevés. De 1980 à 2001, pour toutes les zones et profondeurs pêchées, des grandes raies ont été capturées par sept types d'engins de pêche commerciale, surtout des chaluts à panneaux et des palangres, dans un mouillage d'engin sur 200 en moyenne. Nous utilisons le pourcentage de présence de la grande raie dans les prises pour déterminer son abondance relative en fonction de la température et de la profondeur. Les différences spatiales dans les taux de capture (en poids) traduisent la densité locale ou peut-être la présence de poissons plus gros (plus lourds). Sur l'ensemble de son aire de répartition, la grande raie occupe une large gamme de profondeurs, mais sa répartition selon la profondeur varie d'un secteur à l'autre. Sur l'ouest de la plate-forme Scotian, les taux de capture et le pourcentage de présence de la grande raie étaient environ dix fois plus élevés aux profondeurs dépassant 450 m. Étant donné que 99 p. 100 des mouillages des relevés dans cette région ont été réalisés à des profondeurs inférieures à 450 m, cela indique que les relevés ne couvrent qu'une petite fraction de la répartition totale de la raie dans cette région. Ainsi, les indices fondés sur les relevés sous-estiment l'abondance et ne révèlent pas nécessairement l'évolution de la population; ils témoignent peut-être de mouvements vers la zone du relevé ou hors de celle-ci plutôt que de l'évolution de l'abondance. Pour ce qui est de la température au fond, très peu de grandes raies ont été capturées à une température inférieure à 1,5°C même si une proportion considérable de l'effort de pêche y a été déployée. La grande raie était principalement associée à des températures de 2 à 4,5°C au nord, et de 4 à 9°C au sud. La différence entre les deux régions tient sans doute au fait que la pêche y a été pratiquée à différentes profondeurs (et aux plages de températures différentes qui y correspondent).

Introduction

The barndoor skate (*Dipturus laevis*) is one of a group of similar species that includes *D. batis* in European waters (Brander 1981) and *D. floridana* off the southern United States (Bigelow & Schroeder 1953). It is reported to be is the largest skate in the northwest Atlantic, growing to about 1.5 m in length and 20 kg in weight (Scott and Scott 1988). Its reported range extends from as far north as southwestern Grand Bank and the southern Gulf of St. Lawrence, south to waters off northeastern Florida (Scott and Scott 1988). McEachran and Musick (1975) suggested that the most southerly records may have been misidentified *D. floridana* and that *D. laevis* may not occur south of Cape Hatteras. Within this broad geographic range, barndoor had previously been reported from the tide line (and even reportedly stranded above it in Bigelow & Schroeder 1953) to depths of 430 m.

Off the coast of Atlantic Canada, barndoor skate has never been reported as a common species (in survey or commercial catches) nor has it ever been targeted for exploitation. Kulka et *al.* (1996) reporting on the abundance of barndoor skate relative to other skate species indicated that it was taken in deepwater fisheries on the Grand Banks to the Labrador Shelf. It was most commonly taken in otter trawl fisheries along the outer edge of the shelf. The closure of many of the fisheries in these offshore areas in the early 1990's has meant that the incidence of bycatch species from slope fisheries, including barndoor has diminished since.

Casey and Myers (1998) proposed that barndoor skate abundance was near extinction. This hypothesis was based on analysis of research survey data from the Grand Banks and the Scotian Shelf in Canadian waters and Georges Bank south to the Carolinas in USA waters. Subsequently, in 2000, IUCN (Union for the Conservation of Nature and Natural Resources) listed barndoor skate as Vulnerable based largely on the work by Casey and Myers (1998) and the 2000 assessment of skates in USA waters (Anon. 2000). In 2002, COSEWIC (Committee on the status Endangered Wildlife in Canada) petitioned for a status report of barndoor skate in Canadian Atlantic waters for consideration for listing in 2003.

The purpose of this paper is to examine in greater detail the distribution and abundance of barndoor skate on the Scotian Shelf, Grand Banks, Northeast Newfoundland and Labrador Shelves (Fig. 1) based on bycatch information from fisheries off the coast of Atlantic Canada. This paper provides supplementary information to Simon et al. (2002) that examines recent abundance trends, distribution and sizes of barndoor skate based on research survey data. Using geo-referenced commercial catch data collected by fishery observers, our study looks at distribution and abundance of the species and the relationship to depth and temperature.

Methods

Canadian fishery observers collect detailed, geo-referenced (latitude and longitude), information on the catch, effort and other aspects of the fishing operations in a manner specified in Kulka and Firth (1987). The catch of all species taken in the gear is included in the records along with a geo-reference, depth, time as well as other effort information. From 1980-2001 for the Scotian Shelf north to Lat 71^0 in the Davis Strait, 950,823 commercial fishing sets were observed for trawl (shrimp, otter and midwater), seine

(Scottish and Danish), dredge (scallop and clam), longline and gillnet fisheries plus a few other minor gears.

The fisheries over this period covered much of the shelf area out to the slope but no deeper than 1700 m. Fishing was highly irregular within and between years both in terms of depth and latitude but at least in some years the observed effort covered a substantial proportion of the grounds beyond 200 m and a lesser part of the shallower areas. A gap in records of barndoor skate exists on the nose and tail of the Grand Banks in most years after 1985 because observers were not normally deployed to vessels fishing outside of Canada's 200 mile limit except on the Flemish Cap. Deep water fishing does occur outside 200 miles in all years but the associated data were not available. Thus, the "nose and tail" of the Grand Banks, for the purpose of this study were under-sampled.

Given the relative rarity of occurrences of barndoor skate (less than 200 sets per year on average contained barndoor skate) and variability in locations covered by the fisheries from year to year, data from all years were combined to provide an overview of the distribution of barndoor skate. Catch rate data from the three commercial gears, otter trawl, longline and gillnet that primarily yielded barndoor skate were used to study the distribution patterns in relation to bottom depth and temperature. Given the relative rarity of catches containing barndoor skate, the primary measures used to examine relative abundance, was incidence of occurrence, expressed as percent of sets containing barndoor skate. Catch rates were also calculated, as kg per hour for trawls and dredges, kg per 1000 hooks for longline and kg per 100 nets for gillnet. These values were then scaled to otter trawl catch rate. Given the very similar standardized (scaled) catch rate at depth, the catch rates for the three gears were combined to form a single CPUE standardized to (otter trawl) kg per hour.

Potential mapping in SPANS GIS (Anon 1997) was used to map the distribution of barndoor skate (depicting variation in density) and to perform analyses in terms of distribution in relation to depth and bottom temperature. The potential mapping method converts highly variable point estimates (in this case geo-referenced catch per tow) into categorized catch rate strata. A full description of how this mapping technique works can be found in Kulka (1998).

For the depth analysis, intervals were set at 50 m. Data deeper than 1500 m were grouped because of limited sampling at those depths. Percent occurrence and average catch rate were calculated for each depth interval. Similarly, contours of bottom temperature were created from set records associated with the research survey sets and from data supplied by MEDS (Marine Environments Data System). These long-term temperature means, 1972-1999 and associated geo-reference were converted to temperature surfaces using potential mapping. Fifteen strata of temperatures each with equal areas were created reflecting the range of temperatures observed. The geo-referenced sets were laid over the classified temperature surface and a count of sets and average catch rate were calculated within each temperature stratum.

Given the wide geographical range in the data and the distinctly different temperature regime between areas north and south, comparative analyses were done for the two areas. Two very different sets of conditions in terms of temperature were observed on the Scotian Shelf and southwest Grand Banks. The two areas are defined in Fig. 1, the box

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representing the South area, the remainder of the area referred to in this paper as the North area. Percent occurrence and CPUE in relation to depth and ambient (bottom) temperature was compared between the two areas. Of a total number of 4,700 commercial sets containing barndoor skates 1,323 occurred within the South area (Fig. 1).

Results

Figure 2, a compilation of set locations where barndoor skate were captured as bycatch in commercial fishing gears, from 1980-2001 shows that barndoor skate widely distributed in Canadian waters but generally occur along the slope edge north of the Scotian Shelf and southwest Grand Bank. It's distribution extends much further north than indicated by survey data (Simon *et al.* 2002). At similar depths, barndoor skate show a distribution pattern similar to what was observed for the surveys on the Scotian Shelf and along the southwest slope of the Grand Bank. The commercial bycatch data also shows barndoor skate to be present in deeper waters along the shelf edge as far north as 62^0 Lat., a significant range extension for the species, previously thought to extend no further north than the Grand Banks. The main fisheries that captured barndoor skate north of the Grand Bank were deep water, at depths usually greater than 650 m directing for grenadier and Greenland halibut although they were also taken in smaller amounts in a variety of other shelf edge fisheries and gears (Table 1).

The rate of occurrence of barndoor skate in commercial gears, averaged over all areas, was low. Between 1980 and 2001, only 1 in 200 sets contained barndoor skate (Table 1). However, rate of occurrence was highly variable among years, areas and depths (see depth and area analysis below). Barndoor skate were recorded in 7 commercial gears. While most records were from otter trawl sets, this is mainly because 70% of the total effort observed was for otter trawls. Percent occurrence (percent of sets with barndoor skate to total sets) was highest for longlines (1.9%), more than 3 times higher than for trawls and gillnets. Barndoor skate were captured far less often in other gears. This suggests catchability differs amongst gears and is highest for longlines. Using underwater cameras attached to the head-ropes of standard trawl gear, Edwards (1968) noted that barndoor skate were "extraordinarily adept at avoiding capture" suggesting that barndoor skate are more common than commercial (or survey) trawl catches would indicate.

Catch rates varied little among gears, averaging 47 kg for sets that captured barndoor skate and 0.25 kg per set for all sets observed. Catch rate for sets containing barndoor skate, expressed as weight of catch is not a reliable measure of abundance given that size of individuals caught could affect the magnitude of the catch rate and sets without skate (the large majority) are nor factored in the calculation. However, a 47 kg average catch in sets with barndoor skate indicates that they were usually caught in multiples, occasionally in fairly large numbers (in 45 sets, catch exceeded 500 kg and the largest weight recorded was 4400 kg) but on average, only 1 in 200 sets encountered them. Thus, they appear to form (low density) concentrations which are sporadically distributed along the slope to the north and up onto parts of the shelf to the south. There are no data on sizes caught to determine if the catch rates are influenced by different sizes of fish in the catches among areas.

Fig. 3, depicting catch rates based on weight, indicates some spatial variation (darker shades indicate higher catch rates). Areas of higher catch rates, based on weight may reflect areas of local abundance but could also be the result of the presence of larger fish. Certain areas such as the western extent of the outer Scotian Shelf, the outer Laurentian Channel, the southeast Shoal and parts of shelf edge to the north tended to yield consistently higher catch rates. Temporal trends in distribution are not presented given the high spatial variability in the fisheries (variation in gears used, areas and depths fished) among years.

Both average catch rate and percent occurrence were fairly similar between the North and the South even though average depth and average bottom temperature were substantially different (Table 1, see Fig. 1 for a delineation of North vs. South). To the South, average depth where barndoor skate were caught was shallower and bottom temperature was higher. However, fishing effort was much shallower than to the north, rarely exceeding 450 m whereas fishing to the north occurred as deep as 1700 m.

Fishing effort occurred during all months of the year although effort was greater during the summer and fall (Fig. 4 upper panel). Month of capture of barndoor skate was similar to the overall monthly effort patterns suggesting that there was little seasonal variation in the presence of barndoor skate.

Barndoor skate inhabit a wide range of depths over its latitudinal range. The shallowest record is 27 m although their occurrence was very low at depths < 450 m. They were taken in commercial gears out to the greatest depths fished (Fig. 5). Catch rate and percent occurrence (as well as depths at which commercial gears were fished) were observed to differ between two areas, North and South as delineated in Fig. 1. For these reasons, the two areas were analysed separately. In the North, beyond 450 m, there was a gradual increase in percent occurrence and catch rate, reaching a maximum at 1400 m (Fig. 5, upper panel). In the South, although fishing effort was much higher at shallower depths, both catch rate and percent occurrence of barndoor skate increased rapidly beyond > 450 m and were about 10 times higher than to the North at equivalent depths (Fig. 5, lower panel). Fishing beyond 850 m was limited to a few sets only but the truncation in the values at this depth suggests that barndoor skate are likely present in substantial numbers at depths exceeding 850 m. Thus, barndoor skate were more abundant in the south and peak abundance occurred at shallower depths.

Geo-referenced fishing sets were overlaid on a long term annual mean bottom temperature surface to examine distribution of barndoor skate in relation to bottom temperature (Fig. 6). As was done for depth, the analysis was done for North and South areas. For the North, few barndoor skates were taken where temperature was < 0.9^0C. Catch rate and percent occurrence increased rapidly peaking at 3^0C. A second peak occurred at 4.1^0C then declined to 6.2^0C. A substantial proportion of the North area is associated with bottom temperatures < 0.9^0C but these areas, generally more shoreward yielded no barndoor skate. Very little of the North area is associated with temperatures exceeding 5^0C and this is the reason for the paucity of records above that temperature. To the South, the area where bottom temperatures < 4.1^0C was small. Above 4.1^0C, percent occurrence was table out to the warmest available temperature while catch rate declined with depth.

Discussion

Various authors such as Scott and Scott (1988), Casey and Myers (1998), Simon et *al.* (2002) using research survey data reported the northern limit of barndoor skate as the Grand Banks and that maximum depth to which they distributed was about 400 m. The latter two papers also described trends in abundance using based on the survey data. However, an examination of commercial fishery information (this paper) and comparison to the research survey data provides further insight into the distribution and relative abundance of barndoor skate. Commercial bycatch information gathered by fishery observers provides evidence that barndoor skate extend further in latitudinal and depth range than described by survey data. An examination of commercial fisheries data confirmed what was originally reported by Kulka et *al.* (1996) in a paper describing skate bycatch in commercial fisheries: that barndoor skate are more widely distributed, as far north as the Labrador Shelf to 62^0 N and into depths of about 1600 m.

To the South (Scotian Shelf and southwest Grand Bank), percent occurrence and CPUE in commercial sets at depths < 450 m was only about $1/10^{th}$ the values observed at lesser depths. Given that survey sets to the South rarely exceeded 400 m, this suggests that the area surveyed excludes a significant part of the distribution of barndoor skate on the Scotian Shelf and southwest Grand Bank. To the North (northern Grand Banks, northeast Newfoundland and Labrador Shelves), records of barndoor skate in the surveys is rare. In the commercial bycatch, highest percent occurrence is seen in deep sets (> 1300 m) although neither percent occurrence nor CPUE reach the levels recorded to the South. Thus, barndoor skate appear to be more abundant to the South (highest percent occurrences were recorded on the outer edge of the Scotian Shelf and Georges Bank), reaching their peak abundance there at shallower depths, but outside the area surveyed.

Casey and Myers (1998), their analysis based on survey data showed a decline in the abundance of barndoor skate in the 1950's. They used non-standard survey indices that commenced in 1951on the southern Grand Banks and Scotian Shelf (later in areas to the south) showing that barndoor skate within the area surveyed declined to low levels in the early 1960's, remaining low since. These surveys were conducted mainly at depths less than about 200 m and thus missed a substantial portion of the population (unless barndoor skate were more shallowly distributed in earlier years).

Casey and Myers (1998) also attributed the decline in abundance to over-fishing. However, the buildup of the offshore fleets off Canada and the northeastern USA did not commence until the late 1950's, peaking in the early 1970's whereas the decline occurred largely before that time. Also, most of the fishing effort prior to that time was prosecuted in shallow waters. Thus, both the interpretation of the trends seen in the early surveys and the role of fishing in the decline are in doubt. What is certain is that within the bounds of the survey, density of barndoor skate declined in the 1950's, but the cause(s) are uncertain.

Simon et *al.* (2002) also used survey data to examine recent changes in abundance in the South area. Commercial fishery data shows that a significant portion of the population is located deeper than the area covered by the research surveys, particularly on the Scotian Shelf where survey sets seldom exceed 400 m but the commercial data indicate much higher catch rates occurring beyond those depths. Thus, the recent increase in abundance

survey indices reported by Simon et *al.* (2002) may not reflect changes in the total population if the indices only reflect what occurs on the fringe of the distribution of the species. Thus, both recent and historic trends in survey indices may be representative of only a portion of the population or may even be the result of a shift in depth of the population.

The commercial bycatch data suggest that the non-surveyed and non-fished area may contain a greater part of the population. Given that 99% of fishing effort in the South occurs at depths shallower than 450 m, it is unlikely that fishing mortality has significantly affected the abundance of barndoor skate below those depths (unless barndoor skate regularly migrate into shallower waters). The degree of protection for the population that this "sanctuary" provides is unknown.

Skates in general are considered sensitive to trawl fisheries because of their slow growth, low fecundity and potential damage to eggs (Brander 1981). Walker and Heessen (1996) in examining long term changes in skate populations in the North Sea suggested that un-fished areas may be a source of individuals for re-colonization of fished areas. This may be the case for barndoor skate along their entire distribution, but particularly to the south. Re-colonization of surveyed areas could lead to a faster increase in abundance within the surveyed area than expected. Alternatively if movements across depths was limited, changes in abundance observed in the surveyed area would not reflect changes in the total population. The changes in the abundance of barndoor skate reflected in survey indices must be tempered with the knowledge that the population extends beyond the bounds of the survey.

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Table 1. Inventory of commercial fishing sets containing barndoor skate by gear (upper panel) and by area (lower panel). % of tot effort refers to percent of total sets observed containing barndoor skate. Avg. CPUE refers to average weight (kg) of barndoor skate captured for sets that contained barndoor skate. Refer to Fig. 5 for a spatial definition of North and South areas.

Gear	# sets	% of Tot Effort	Avg Cpue	% Occurrence
Midwater trawl	4	0.09%	30.0	0.05%
Dredge	8	0.17%	73.4	0.03%
Scottish Seine	10	0.21%	14.0	0.39%
Gillnet	76	1.62%	92.0	0.57%
Shrimp trawl	445	9.47%	27.4	0.23%
Longline	905	19.26%	41.5	1.89%
Otter trawl	3,252	69.19%	49.5	0.55%
All	4,700		46.5	0.53%

Area	North	South	3M	All
# of sets	3,178	1,462	60	4,700
Mean CPUE	44.36	52.77	9.47	46.53
% Occurrence	0.62%	0.39%	0.30%	0.53%
Avg Temperature	2.3	7	4.2	3.6
Avg Depth	764	233	382	595

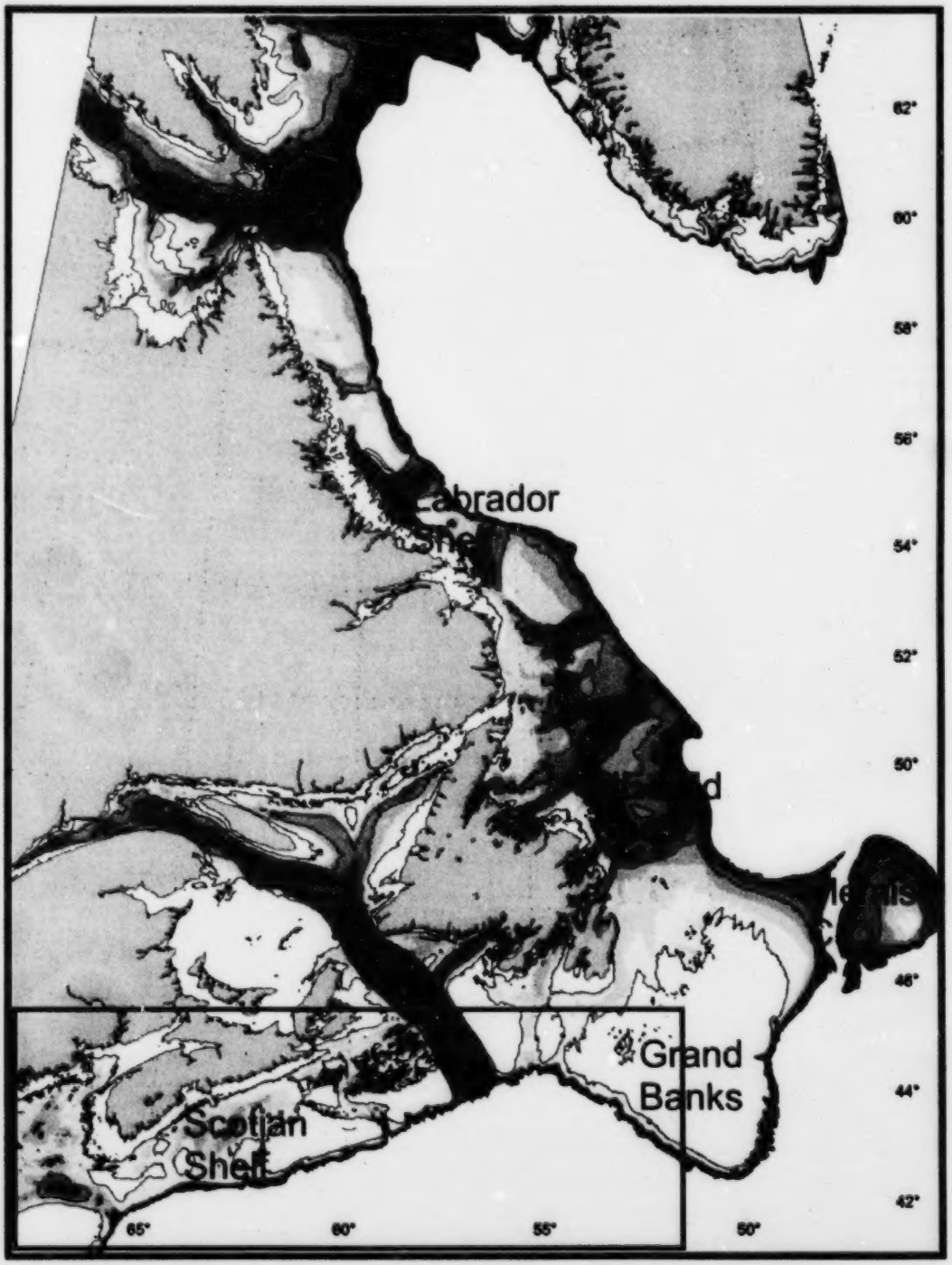

Figure 1. Map of the Northwest Atlantic off the coast of Canada showing bathymetry and shelves. Grey shades denote depth zones by 50 m intervals out to 450 m, 100 m intervals from 500 to 1000 m, 1000-2000 m and 2000-3000 m. The box delineates South (inside the box) from North, the two areas differentiated in the analyses.

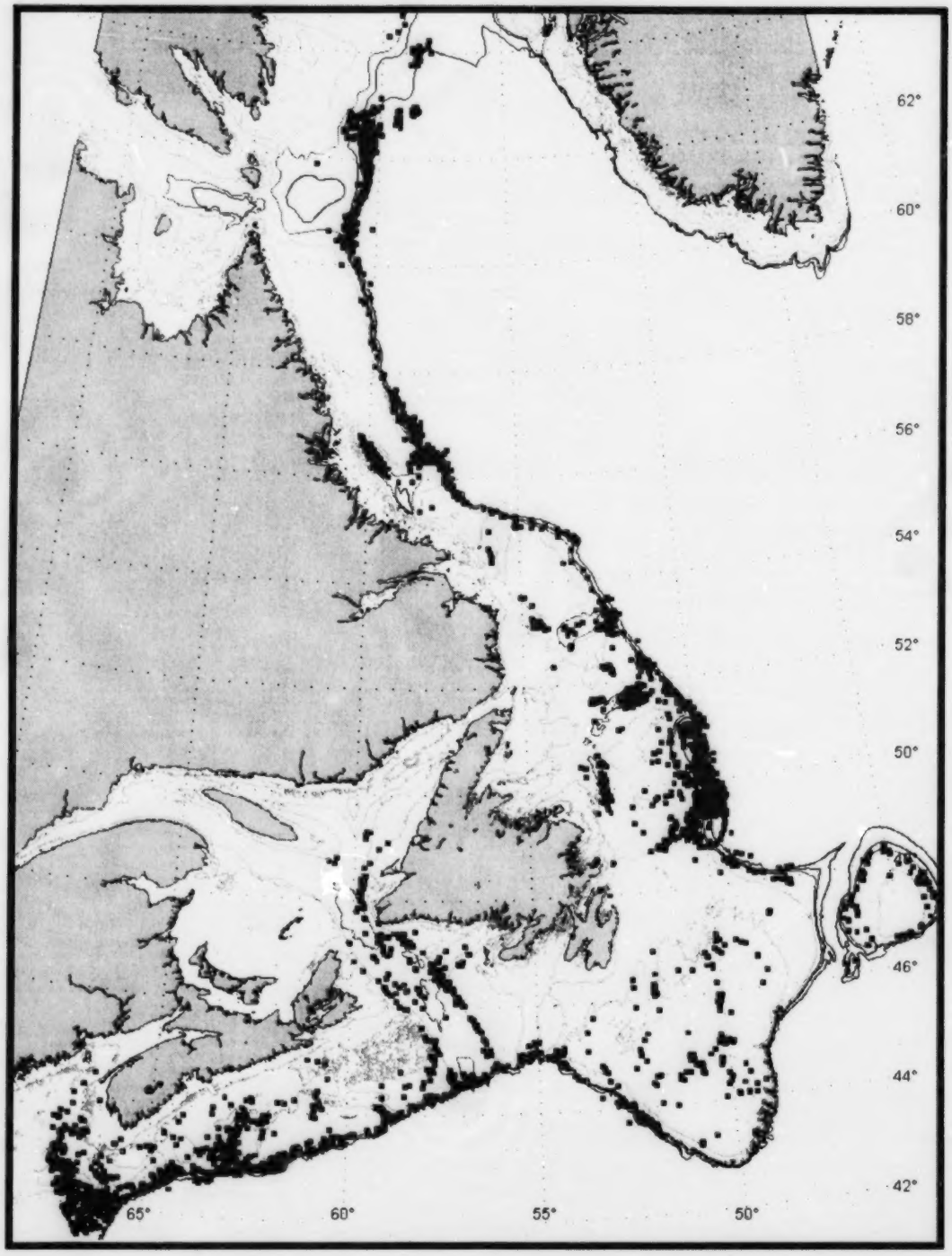

Figure 2. Location of fishing sets that captured barndoor skate, 1980-2001. Lack of observer coverage on fisheries outside of Canada's 200 mile limit (eastern Grand Bank) resulted in few records in that area.

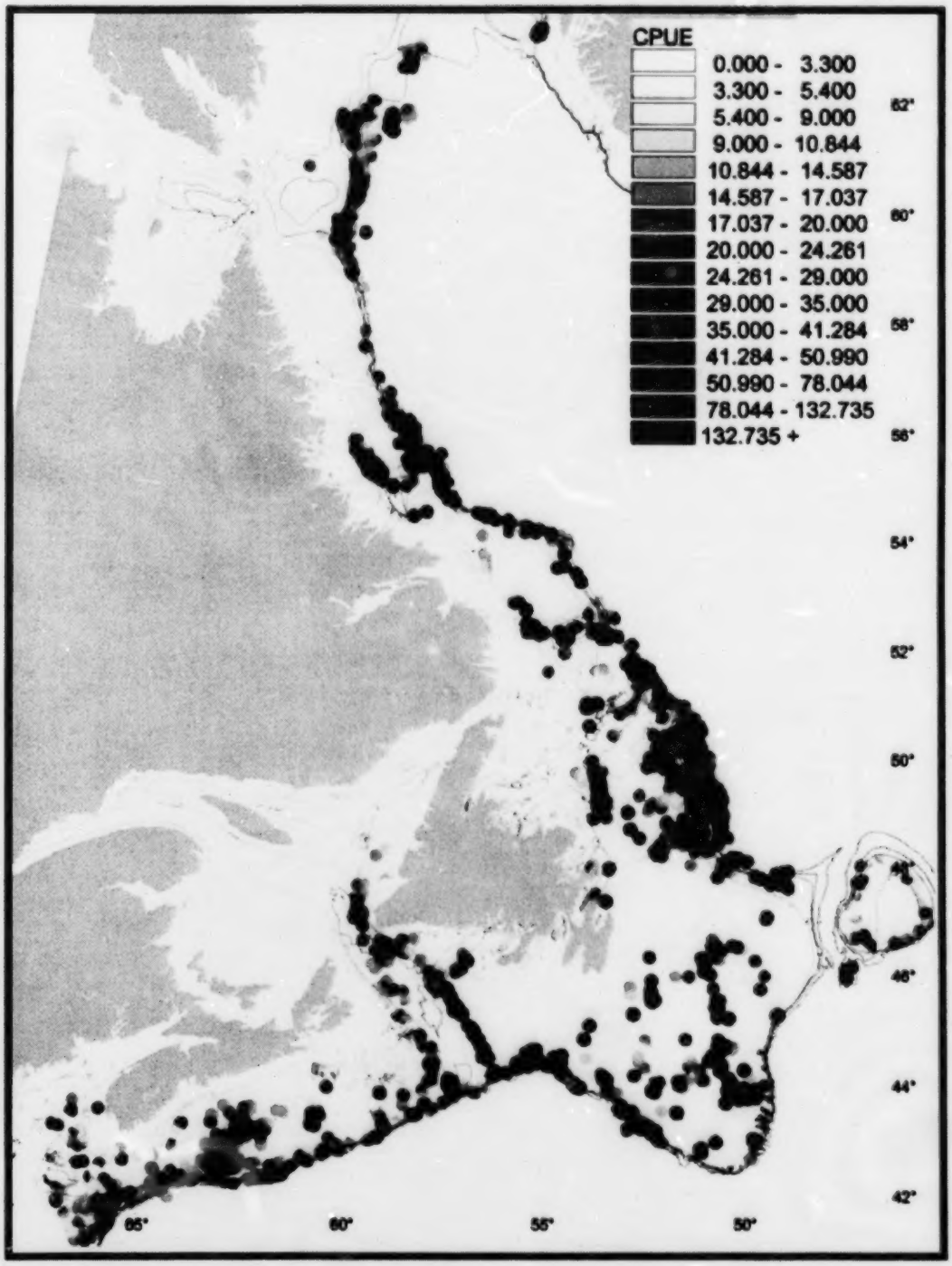

Figure 3. Catch rate of barndoor skate taken in commercial fisheries. 1980-2001. CPUE is scaled to otter trawl catch pr hour expressed in kg.

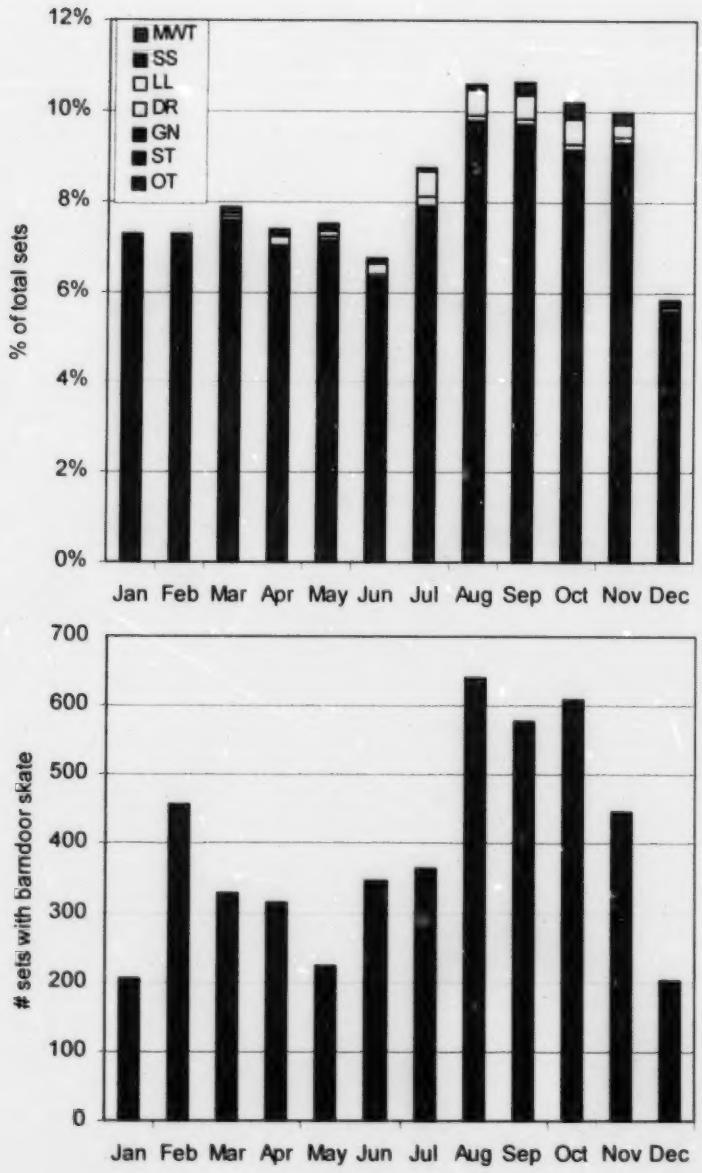

Figure 4. Seasonal variation in fishing effort ex pressed a a percent of total effort, 1980-1991 (upper panel) and the sets containing barndoor skates (lower panel).

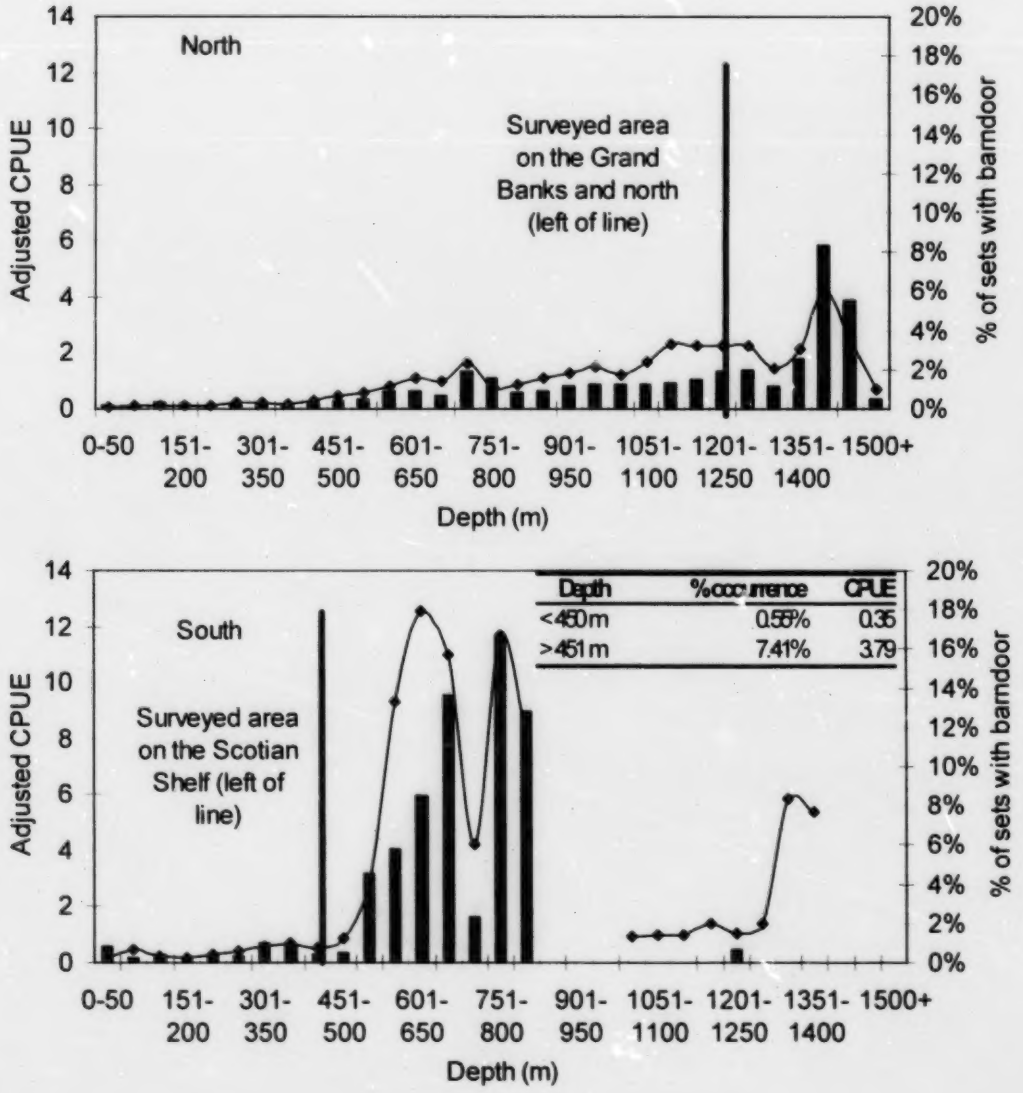

Figure 5. Catch rate and percent of sets containing barndoor skate in commercial fishing catches from 1980-2001 with respect to depth fished. Top panel shows northern locations and bottom panel, the southern locations. Refer to Fig. For a spatial definition of areas. Lower table summarizes percent occurrence and catch rate at two depth zones.

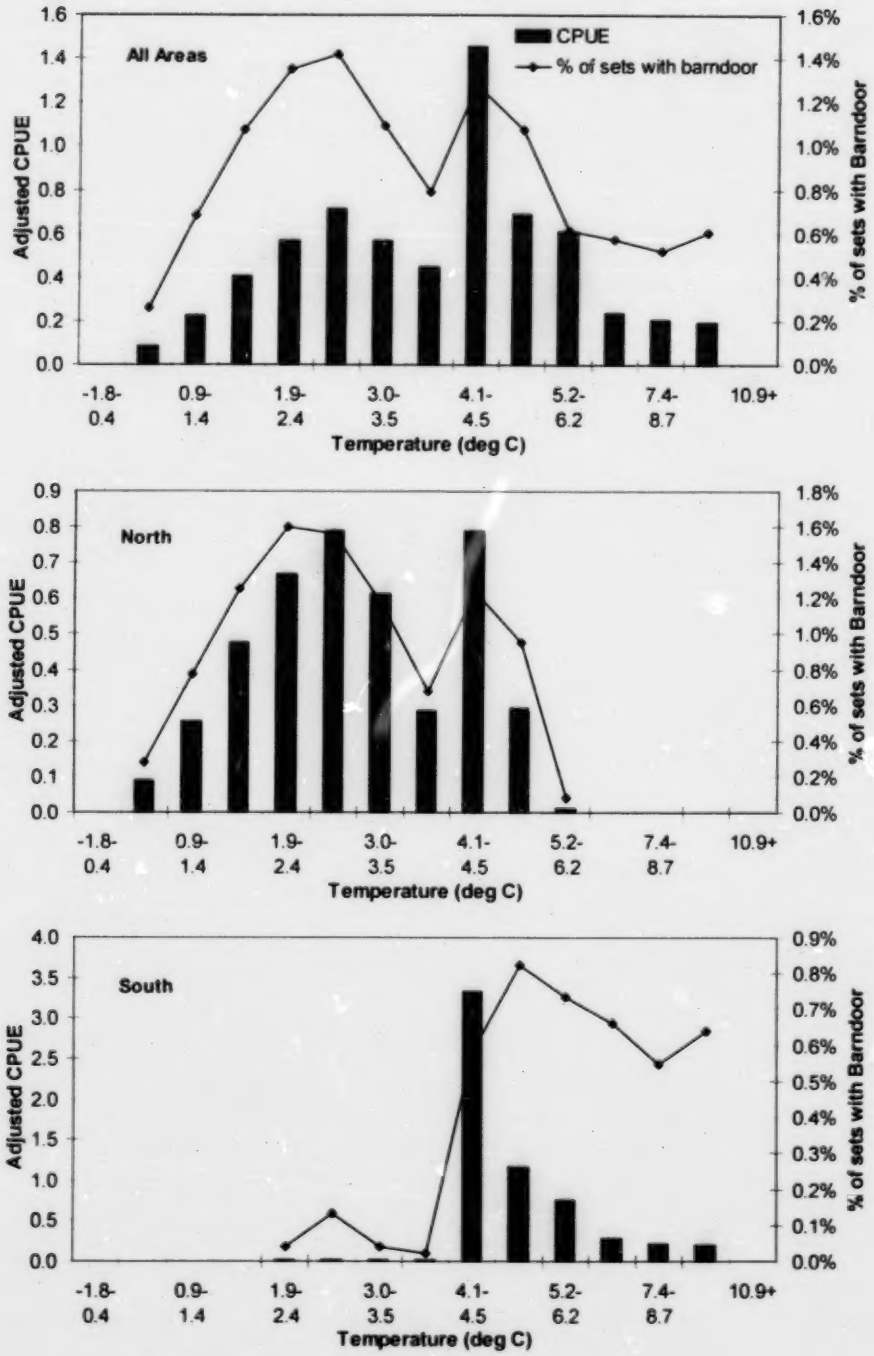

Figure 6. Catch rate and percent of sets containing barndoor skate in commercial fishing catches from 1980-2001 with respect to bottom temperature of area fished. Top panel is for all areas, middle panel for northern locations and bottom panel, for southern locations. Refer to Fig. 1 for a spatial definition of North and South areas.